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U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 57.
B. T. GALLOWAY, *Chief of Bureau.*

METHODS USED

FOR

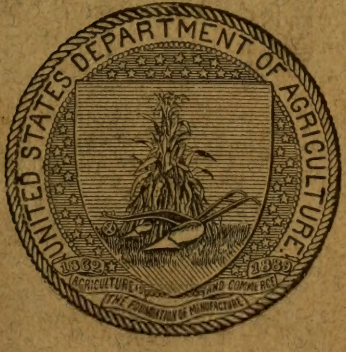
CONTROLLING AND RECLAIMING SAND DUNES.

BY

A. S. HITCHCOCK,
Assistant Agrostologist, in Charge of Cooperative Experiments.

GRASS AND FORAGE PLANT INVESTIGATIONS.

Issued March 10, 1904.



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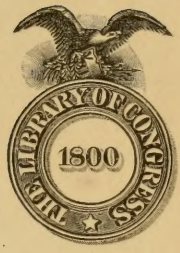

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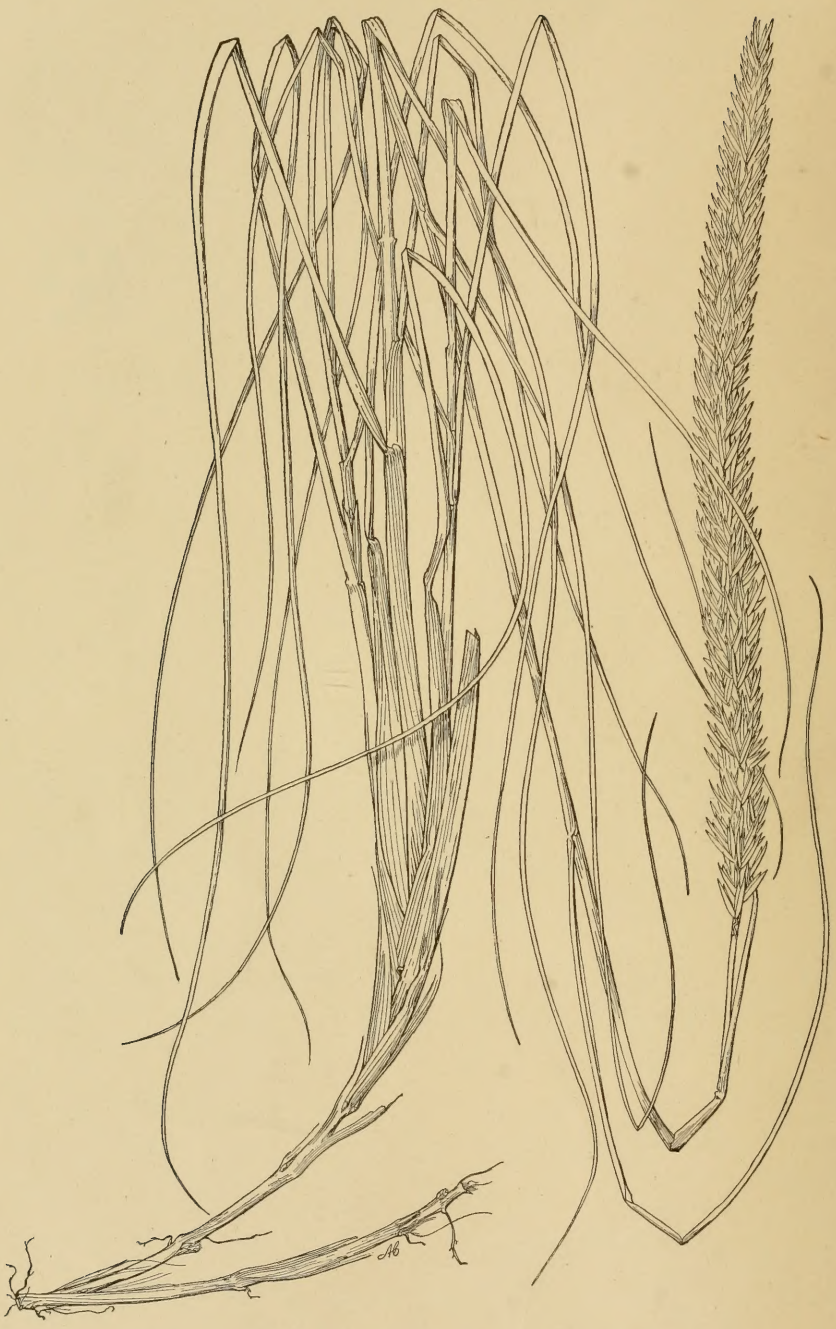

BEACH GRASS (AMMOPHILA ARENARIA LINK).

U. S. DEPARTMENT OF AGRICULTURE.

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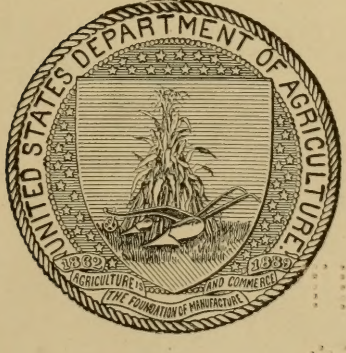

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BUREAU OF PLANT INDUSTRY.

BEVERLY T. GALLOWAY, *Chief of Bureau.*

GRASS AND FORAGE PLANT INVESTIGATIONS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., January 7, 1904.

Sir: I have the honor to transmit herewith a paper on "Methods Used for Controlling and Reclaiming Sand Dunes," and respectfully recommend that it be published as Bulletin No. 57 of the series of this Bureau.

This paper was prepared by Mr. A. S. Hitchcock, Assistant Agrostologist, in Charge of Cooperative Experiments, Grass and Forage Plant Investigations, and has been submitted by the Agrostologist with a view to publication.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

On the Atlantic and Pacific coasts, on the shores of the Great Lakes, and at numerous places inland, there are areas of sandy land, for the most part originally covered by vegetation, but now denuded of plant growth through the shortsighted policy which has so often prevailed in this country of utilizing everything in sight without reference to the future. The Department of Agriculture is frequently called upon for advice concerning the proper methods of controlling this sand and preventing it from drifting. In some cases cultivated fields have been invaded and railroad tracks covered. The sand has even invaded cities, covering up houses and filling the streets, and much valuable property has thus been destroyed.

Much work has been done in controlling shifting sand dunes in Europe during the past century, and methods have been developed whereby it is possible to control the sand and in many cases to cover it again with vegetation. On account of the importance of the subject, Prof. A. S. Hitchcock, of this office, was sent to Europe recently to study the methods there used in this work. In the autumn of 1902 he visited the Netherlands, Denmark, Germany, and France for this purpose. An outline of the methods that have been successfully employed in those countries is given in this bulletin, together with some other information of general interest concerning the subject of sand dunes.

W. J. Spillman,
Agrostologist.

Office of the Agrostologist,
Washington, D. C., December 16, 1903.

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METHODS USED FOR CONTROLLING AND RECLAIMING SAND DUNES.

INTRODUCTION.

The sand-dune areas of Europe are of especial interest because they present conditions similar to those found in the United States and because it is there that the methods of reclamation were first applied and later most successfully developed.

In order to investigate the methods used and determine to what extent they might be applied in this country, the writer visited several regions in Europe where the conditions and methods may be considered representative—the Netherlands, Denmark, the southwest coast of France, and the Kurische Nehrung on the northeast coast of Germany. In Prussia much work has been done along the coasts of the Baltic and North seas, but this is so well described in Gerhardt's[a] admirable book upon the dunes of Germany that other points than the ones mentioned were not visited.

There are other localities of minor importance where dunes occur and where efforts toward reclamation have been made, but it was not learned that the methods used differed essentially from those investigated. Lack of time prevented visits to certain other interesting interior regions, such as the Banat plain of southern Hungary, the north shore of the Black Sea, and Russian Turkestan. The last two regions are of importance because of the efforts put forth by the railroads to prevent the enroachment upon their right of way by shifting dunes.

FORMATION OF SAND DUNES.

Sand hills or dunes usually occur along a sandy seacoast. The sand is constantly washed up by the waves and when dry is readily carried inland by the wind. On a rocky or marshy coast this does not occur.

[a] Paul Gerhardt, Handbuch des deutschen Dünenbaues, Berlin, 1900. This is a very complete and detailed account of the sand dunes of Germany, including geology, flora, formation, reclamation, and historical notes, and is the most elaborate work of this nature thus far published. The writer is indebted to this work for the text figures used in this bulletin. Mr. Gerhardt was superintendent of the Königsberg district (Regierungs und Baurat) and was later advanced to the charge of the entire work at Berlin.

Under the action of the wind the sand accumulates in ridges or hills of irregular contour and extent, depending upon the force and direction of the prevailing winds. It is not intended here to go into the details of dune formation, a subject which has been elaborated in Gerhardt's book and also in numerous lesser works. Suffice it to say that ordinarily a dune passes through a rather definite series of changes. It is formed near the beach and travels back toward the interior. A typical wandering dune presents a gradual slope toward the wind and an abrupt slope on the lee side. The wind forces the sand up the slope and it falls over the edge. The hill or ridge then travels in the direction of the prevailing wind at a rate depending on the force and constancy of the latter. Such a hill is called a wandering dune. As the dune recedes from the coast a new one may form at the beach.

Upon the wandering or active dunes the sand is shifting to such an extent that vegetation does not establish itself. Consequently such dunes are bare. During wet periods seeds may germinate, but sooner or later the flying sand destroys the plants either by cutting them off as by a sand blast or by burying or uncovering them. However, as the action of the wind becomes less forcible at a distance from the strand, vegetation is at last able to become established and resist the enfeebled sand blast. A wandering dune is thus gradually converted into a fixed dune, which, if left to itself, finally becomes forested.

Similar dunes are often formed along the larger rivers or on interior sandy wastes such as are found in the central portions of the Netherlands and Denmark. It not infrequently happens that a fixed dune becomes converted into a wandering dune. This occurs through the removal of the vegetation, either by natural means or as the result of man's carelessness. The result in the first case is usually brought about by changed conditions, such as the direction of the wind, whereby the vegetation dies in certain spots and "blowouts" are formed. Such cavities or blowouts gradually enlarge as the surrounding vegetation is undermined and the result may be the birth of a wandering dune. But from an economic standpoint by far the greatest harm has come from the removal of forests from fixed dunes. The Kurische Nehrung in Prussia and the coast dunes of the Netherlands were at one time covered with forest and gave no trouble. Other cases are known where dunes held permanently by a covering of grass have been converted into wandering dunes by the pasturing of cattle upon them, thus cutting up the sod.

Sand dunes of any considerable extent are rarely found along the seacoast in warmer regions, because the long growing season is more favorable to vegetation. The forest, or at least a scrubby growth of shrubs, usually comes down close to the high-water mark. The severe winter storms of the high latitudes are chiefly responsible for the great dune areas of the north.

In many cases the wandering dunes encroach upon arable land, upon forest, upon valuable property such as railroads and buildings, or upon rivers, harbors, or other water ways. This usually indicates that there has been a recent change of conditions resulting in the formation of active dunes. Seaside resorts upon sandy beaches are often seriously damaged by the formation of dunes and blowouts upon various portions of the property.

In addition to the trouble arising from the encroachment of sand at points where it does damage, it should be understood that there are large areas of sandy land consisting of dunes in various stages of fixation, interspersed with portions of level and sometimes arable land. These level spots represent portions where the wind has swept away the sand down to moist soil, which usually has a definite relation to the water level. Such areas of dunes may include many square miles and are useless for agricultural purposes. It is thus seen that the fixation of dunes may be for two purposes—to protect property in the lee or to convert a useless area of waste land into a productive forest.

ACTION OF THE WIND UPON DRIFTING SAND.

When the wind sweeps over a free surface of drifting sand it acts about equally throughout; but an obstruction of any kind, such as a log or a bunch of grass, at once modifies the action of the wind. A solid object increases the force of the wind around the sides, and hence the sand is excavated. In the lee of the object the sand will accumulate. If two such obstructions are near together a channel is formed between them and once formed deepens with astonishing rapidity. The carrying power of the wind increases much more rapidly than the increase in the velocity.[a] Consequently, any increase in the velocity is immediately noticeable in the increased erosive power. The erosive power of the wind is not identical with the carrying power, for in the first case the wind overcomes cohesion and in the second case it overcomes weight. If the velocity of the wind decreases, the sand previously held in suspension is deposited.

If a solid fence is placed upon the sand at right angles to the wind

[a] Theoretically the transporting power of the wind varies as the sixth power of the velocity—that is, if the velocity is doubled the carrying power is 64 times as great. It is clear that the force exerted by the wind upon a fixed surface increases as the square of the velocity, for if the velocity of the wind is doubled there will be twice as much air striking the surface with twice the velocity. Furthermore, if the velocity remains the same the force exerted increases with the surface—that is, with the square of the diameter. The moving power then varies as the product of the square of the velocity and the square of the diameter. But the force or work done, which is the same as the weight of the object transported, varies with the cube of the diameter; or, putting it all in terms of velocity, the force varies as the sixth power of the velocity.

the sand is excavated in front (fig. 1). The wind, unable to proceed, is divided into currents in all directions. Those going downward scoop out the sand, thus forming a drift a short distance in front. This increases until its height equals that of the fence, when the wind, no longer meeting with the obstruction, allows sand to be deposited

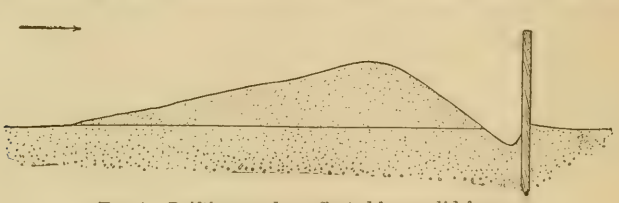

FIG. 1.—Drifting sand as affected by a solid fence.

in this channel, and it fills up, covering the fence. Similarly at the ends of the fence the wind currents are increased and the sand is scooped out. If the fence is raised so as to allow a space beneath, the sand is rapidly scooped out below. The same result occurs beneath buildings, trestles, or other works which allow a space beneath,

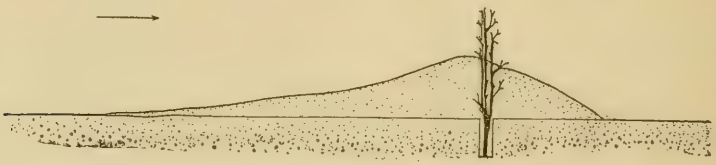

FIG. 2.—Drifting sand as affected by an open, inflexible obstruction.

through which the wind rushes with increased force. If, however, the obstruction is not solid, but more or less open, as a pile of brush or a bunch of grass, the action is entirely different. The wind passes through the obstruction, but with decreased velocity; hence, sand is deposited within the obstruction. No excavation takes place in front

FIG. 3.—Drifting sand as affected by an open, flexible obstruction.

or around the sides. If the obstruction is stiff and inflexible like a sand fence, the sand is deposited on both sides (fig. 2), the windward slope being gradual and the lee slope more abrupt. If the obstruction is flexible like a bunch of grass, most of the sand is deposited in the lee (fig. 3). Of course there are all gradations between the two classes, and various circumstances may modify the usual action.

It may be further stated that when the wind is blowing up an

incline, the surface velocity increases with the steepness. A small object is easily blown uphill. But when the wind blows down a slope, eddies form which usually produce a current uphill at the surface. Thus it happens that while small bodies can be blown uphill easily it is not often that they are blown downhill, but must fall from their own weight when the slope is steep. The fact that the velocity of the wind at the surface on the windward side of a dune increases with the slope results in producing a normal incline, which represents a balancing of forces. Usually this incline is quite gradual compared with the lee side of the dune, where the slope is the greatest at which the sand will remain in place—about 30°.

Sand can be removed from one place to another farther on by placing a suitable obstruction above, with a space between it and the surface of the sand, which will increase the wind velocity at this point. Sand may be filled in at any point by interposing an open obstruction, such as brush or a sand hedge, or by planting grass. The practical application will be referred to farther on.

ARTIFICIAL FIXATION OF DUNES.

The fixation is most permanent when the dunes are covered with forest; hence, forestation is the ultimate aim wherever possible. But there is a narrow strip of territory just back of the strand where trees will not grow on account of the exposure to the severe winds and the action of the ocean spray. The width of this strip depends upon local conditions and may vary from one to several rods. The force of the wind is influenced by the character of the coast. Experience soon demonstrates how near to the strand a forest may be produced.

When the work of fixation is completed there will be a forest over the greater part, but a strip along the coast remains which must be permanently held in place by some other method, usually by the planting of grass. When the forest is once established it is cared for and preserved according to the usual methods of forestry. Usually it is impossible to establish a forest directly upon the sand dunes either by sowing the seed or setting out young trees, because the drifting sand cuts the leaves and bark or uncovers or buries the young plants. Sowing the seed has been tried several times, but there remain of this work only a few scattered patches of trees in protected places. It is therefore necessary to hold the sand in place by some kind of a covering until the trees can obtain a start, when they form a covering themselves.

The work of fixation is thus divided into two rather distinct stages: (1) Preliminary; holding the sand in place. (2) Permanent; establishing a forest. Upon the coast strip the work does not proceed beyond the first stage, but the maintenance of the covering in a satisfactory condition requires constant care.

BINDING THE SAND.

There are many methods which have been employed at various times, but those now in successful use on a large scale may be considered under three heads: (1) Transplanting sand-binding plants upon the dunes, sufficiently thick to form a living cover; (2) covering the entire surface with some inert material which prevents the wind from reaching the sand, and (3) covering the surface with a network of brush fence which, while not preventing the wind from reaching the sand, lessens its velocity and prevents drifting. It may be remarked that numerous experiments have demonstrated the futility of sowing the seeds of any plant directly upon the unprotected surface of the bare sand.

These methods, as they have been finally elaborated, will now be described. For the historical development and the description of special methods to meet unusual conditions, the reader is referred to Gerhardt's book previously mentioned.

BINDING BY MEANS OF GRASSES.

Various plants for binding the sand have been tried, but none have been found so successful as grasses. Willow cuttings have been employed in a few cases, but their use has not proved satisfactory. Of the grasses the species used almost exclusively is beach grass (*Ammophila arenaria* Link), shown in Plate I, frontispiece. A kind of wild rye (*Elymus arenarius* L.) has been used occasionally. Beach grass grows naturally on the dunes all along the north Atlantic coasts of both Europe and America as far south as Morocco and North Carolina. It grows in clumps to the height of one to three feet and spreads by means of extensively creeping underground stems or rhizomes.

An important character of beach grass is that it grows with most luxuriance where the sand is drifting. In quiet sand it persists for a few years but gradually dies out. The drifting sand seems to supply the conditions for continued rejuvenation of the growth as the sprouts force their way up through the accumulating sand.

Transplanting.—Beach grass may be transplanted in the autumn or spring; in the autumn from the time it is mature, which may be as early as September, until the ground freezes, and in the spring from the time the ground thaws until growth starts. The grass is usually transplanted in the autumn, because at this time the requisite labor is more easily obtained, and furthermore it is then easier to pick out the individuals that are at the right stage of growth. It is best to choose moist or foggy weather, as the plants are more certain to grow, the danger of desiccation is less, the sand being damp it is more easily manipulated, and the work can be performed much more comfortably,

as the flying sand seriously interferes with planting during dry weather.

The plants chosen for transplanting should be two years old and have at the base one or two nodes. The roots spring from these nodes; consequently at least one node must be present. More than two are not necessary and would be a waste of material, though they do no other harm than to interfere with planting in proportion to their number. One-year-old plants are not strong enough and have not developed the nodes sufficiently for transplanting. Plants more than two years old are proportionately lacking in vitality and do not throw out roots with sufficient vigor. With some experience laborers are able to distinguish at sight plants of the right age. If the grass is growing in loose sand and has not been covered deeply, it may be pulled up by hand. But usually it is necessary to cut the rhizomes below the surface of the sand, after which the plants can be easily pulled up. The method of procedure is for the workman to seize a suitable clump of the grass with the left hand and with a spade held in the right hand strike into the sand in such a manner as to cut off the rhizomes below having one to three nodes at the lower end (Pl. VII, fig. 1). The bunch is then pulled up and placed in a pile or under the left arm. When a bundle has accumulated, it is tied up and is ready for use. The spade used is a light tool specially made for the purpose, with a sharp edge or point and a short handle. Sometimes an ordinary spade, such as is used in digging, is put to this service.

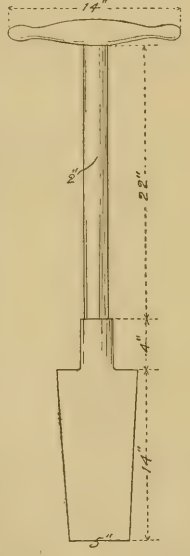

FIG. 4.—Spade used for planting beach grass.

If the grass for transplanting is taken from the dunes that are to be fixed, care should be taken not to remove too much from one place and allow the wind to make a blowout. It should be chosen from places where the grass is growing too thickly. The arrangements should be such that the grass can be planted soon after being dug or the roots may dry out too much. For the same reason it is best to dig the plants near the place where they are to be set out, thus reducing the distance of transportation.

The grass may be set out in various ways, but the method which seems to be most satisfactory is as follows: The planting is done by two persons working together. One prepares the holes and the other inserts the grass. The holes are made with a spade specially constructed, as shown in the illustration (fig. 4). The blade is rather heavy and has a sharp edge below. The operator lifts the spade by the cross bar or handle with both hands, and allows it to drop into the sand mostly by its own weight. He moves the handle back and forth once

or twice, or until the blade has been worked down through the sand to the required depth. This makes a V-shaped opening in the sand 8 to 12 inches deep. The sand must be moist enough to retain its position or this method can not be used. The second worker now takes a portion of grass sufficient for one planting and places it in the hole, flattening out the bunch properly. The first worker puts the spade in the sand just behind the bunch, pushes the sand up tightly against the grass, and the operation is completed (fig. 5). The grass can be set out quite rapidly in this manner (Pl. VII, fig. 2).

Arrangement of the plantation.—If the dunes are already partially covered with beach grass, it may be necessary to plant only here and there in the bare places to prevent excavation by the wind or the formation of blowouts. If the sand is bare or covered with only a scattering growth, it is necessary to plant systematically. The most common method is to set the plants in rows. In Germany they are set in squares, the quadrat system, which will be described under methods used in the Kurische Nehrung. When the grass is set in rows, the bunches are placed so that they alternate in adjacent rows. Ordinarily the rows are fairly straight and perpendicular to the prevailing direction of the wind. In an extended area, where there is a succession of dunes and depressions, the rows may follow the contour lines. Rows in the direction of the wind should be avoided, as a channel will be formed between. In broken dune areas the plantings are made between the dunes and along their slopes, but leaving the tops bare (Pl. IV, fig. 1).

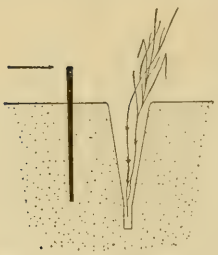

FIG. 5.—Method used in planting beach grass.

Usually there is no preparation of the dunes in the way of leveling or filling, as it is found more economical to allow the wind to do this work. The idea is to accumulate sand in the channels and hollows and allow the wind to blow off the tops of the hills. To aid in leveling the high places the grass is removed from these so that the wind can have free access. No planting may be necessary in the low places where the sand has been blown off down to moisture, as such situations support considerable vegetation. The planting is begun at the base of the slopes and proceeds toward the top, as it is the lower portions that are eroded the most rapidly, for the reasons stated when discussing wind velocity.

The thickness of the planting depends upon local conditions. If it is necessary to accumulate sand rapidly, as in filling a channel, the grass is planted in large bunches placed closely together; but where the sand is easily accumulated, the grass is set thinly to prevent its being covered. Under average conditions the rows are 15 to 18 inches apart and the plants about a foot apart in the row. The amount

of grass in a bunch is about what can be easily taken in the hand and may consist of four or five stalks.

Formation of the barrier dune.—The grass planting previously described applies particularly to the large dune areas near the coast,

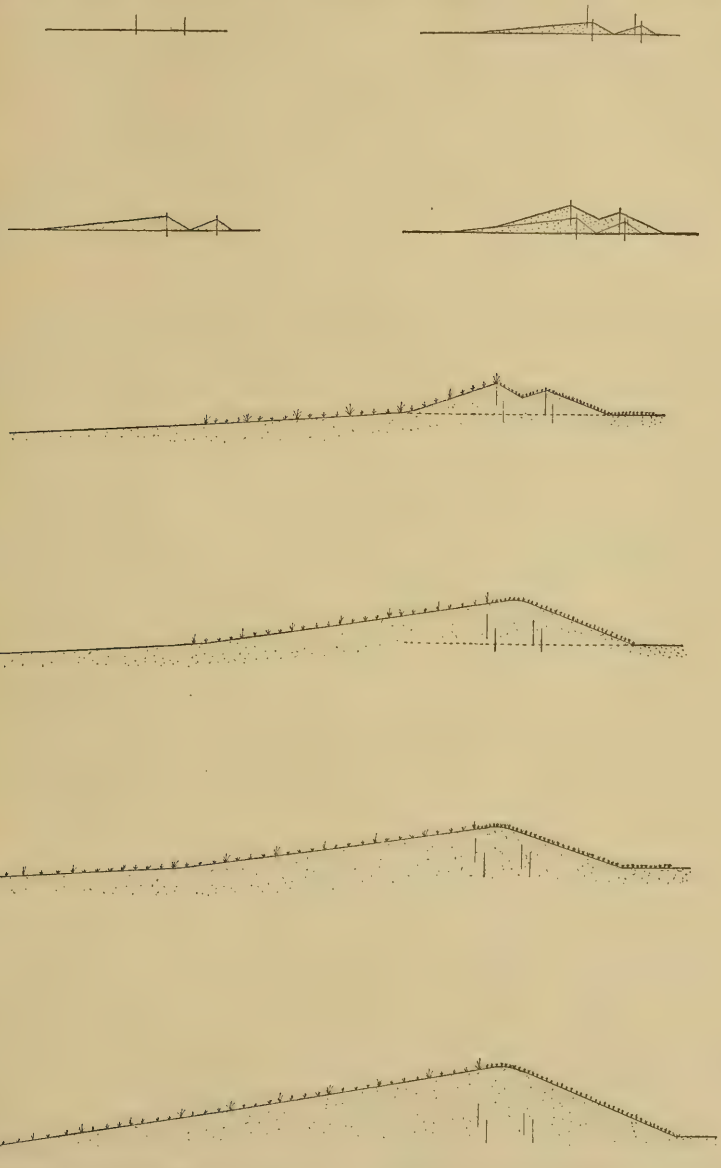

FIG. 6.—Diagram showing in cross section the successive steps taken in forming a barrier dune. The strand is at the left.

where this process is preparatory to the planting of trees. The function of the grass has been fulfilled when the forest is established.

As stated in an earlier paragraph, there is a strip of sand along the

coast just back of the strand which presents conditions unfavorable to forest growth. Here it is necessary to hold the sand in place permanently by means of the grass. To do this requires constant supervision. Through various causes bare spaces are likely to occur which must be replanted to prevent the formation of blowouts. Sometimes the bunches must be thinned, as the presence of two large adjacent bunches may cause the wind to draw through between them and form a channel.

FIG. 7.—Repairing a small breach in a barrier dune by planting grass.

On the Kurische Nehrung in Prussia and along the southwest coast of France it has been found advisable to form an artificial protecting dune extending all along the sea in front of the forest (Pl. VI, fig. 1). This dune is produced by accumulating the sand rapidly so as to form a long ridge (fig. 6). For this purpose brush fences, which consist of rows of brush or rough branches driven into the sand firmly but rising above the surface about 30 inches, are used. The tops should be on a level. Two such rows are placed about 6 feet apart. These fences allow the wind to pass through, but reduce its velocity, and hence sand is deposited within and on both sides. When the sand has reached the top of the fences, a second pair is placed above. When a ridge has been formed, beach grass is planted in rows parallel to the crest. At first, plantings are made along the slopes and a short distance in front toward the strand. As the sand accumulates, the grass is planted farther to the windward. Finally the protecting dune assumes a comparatively permanent form, with a long slope to windward (toward

FIG. 8.—Repairing a larger breach by means of sand fences. The diagram represents a cross section of a dune with two rows of sand fence parallel to the dune and cross rows extending from the outer row to the broken face.

the sea) of 4 to 5 degrees, or about 1:9, and a steep slope on the lee side of about 1:2 (Pl. V, fig. 1). As a matter of fact, the windward slope is often much steeper—as much as 1:6 or even 1:4.

In practice this protecting dune must be established upon an area more or less broken by dunes of irregular shape. The ground line for the ridge is laid out to follow the coast in a general way, but to avoid all sharp bends or indentations of the shore line. The hollows and channels are filled up to the desired height, while the peaks and any small dunes lying in front are denuded of grass so that they are

ultimately removed by the wind. Such a ridge protects the forest or arable land lying in the lee, but requires constant supervision to keep it in repair. The danger is from encroachment of the sea during storms, especially in winter. A single severe storm may break through and destroy several rods of well-built dune. Such a breach must be repaired as soon as possible, or the wind will still further erode the unprotected sand and enlarge the opening. These breaks are best filled in by means of sand fences (figs. 7 and 8 and Pl. IV, fig. 2).

It may be mentioned here that reclamation of sand dunes on a large scale is carried on in Europe by the general governments, as private individuals lack the necessary unity of purpose. This will be touched upon under the head of the particular regions visited.

BINDING BY MEANS OF HEATHER.

As stated previously, it is necessary to hold the sand in place while a forest is being established. Near the seacoast this is usually done by planting the beach grass, which is found growing wild upon the dunes. There are, however, vast stretches of inland dunes where beach grass does not grow, and the cost of transportation renders this method less economical than others. When fixing the sand is but preliminary to planting trees the method used depends upon the relative cost. Along the coast, where the fixation is permanent, the planting of beach grass is the only method which meets the requirements, and hence it is used even when it becomes necessary to import the plants.

For a temporary covering any cheap inert material which meets the condition, such as brush, straw, or sawdust, may be used, but by far the most satisfactory material in northern Europe is the heather (*Calluna vulgaris* Salisb.). As it is a common plant in the sand-dune regions this method is used in the central portion of the Netherlands and in the interior regions of Denmark (Pl. III, fig. 2). The heather can be used also in areas near the seacoast, as in western Denmark.

Laying the heather.—The heather is cut off with scythes, spread over the surface, and held in place by a little sand. The scythe used for mowing is short and somewhat resembles American brush scythes. The heather is then tied in bundles and carried to the place where it is to be used. Sometimes it may be necessary to transport the bundles some distance, as the heather grows usually only in the low places between the dunes, or at least it is here that it grows in sufficient luxuriance to be cut profitably. Since the heather is not planted, it is not necessary to use it immediately after gathering, as in the case of the grass. The plants are spread out flat upon the surface, overlapping each other in the rows, and are held in place by being partially covered with sand. The surface is not prepared, except that small inequalities are leveled so that the wind can not get beneath the layers of heather (Pl. II, fig. 1).

The heather is also used in road making. The roads through the dunes are laid out and graded in the usual manner, after which heather is laid thickly in courses upon the surface, thus preventing the wheels of vehicles from sinking into the sand (Pl. II, fig. 2).

BINDING WITH SAND HEDGES.

Sand hedges are used for binding when other methods are not practicable, or where the sand is drifting with especial force, or where it is desired to accumulate sand with rapidity. In general this method involves the use of some inert material, like brush or rows of stakes or reeds, which projects above the surface of the sand and reduces the velocity of the wind without causing deflecting currents, which erode the sand. The entire surface of the sand is not covered, but the action of the wind is hindered sufficiently so that the sand present remains in place and additions from the strand or from neighboring unprotected areas are accumulated (Pl. IX, figs. 1 and 2).

The sand fences or hedges are made from brush obtained in the forest. The branches are cut into pieces from 18 inches to 2 feet long, with sharp ends. The ends are sharpened by the slanting stroke which severs the stick. The side twigs are cut off roughly. These stakes are driven into the ground in rows, or, still better, in squares, thus catching the sand from all directions. The stakes project above the surface about a foot and should be on a line at the top, parallel with the general plane of the dune surface. The size of the squares depends on the tendency to drift, and varies from 9 to 12 feet. The rows should be at right angles to the direction of the prevailing wind. On dunes near the shore the rows should run parallel to this, with the short rows perpendicular. In covering a surface the long rows are first placed and the squares made by inserting crossrows between. The stakes should be close enough together in the rows so that the average width of the space is about equal to the average diameter of the stakes. The size of the stakes varies from half an inch to 2 inches (Pl. IX, fig. 1).

The common reed of Europe is utilized in the same manner. It is cut into the proper lengths and the pieces are set out in rows by about the same methods used in grass planting (Pl. IX, fig. 2).

As previously stated, sand fences are used to repair breaks in protecting dunes, to fill channels previous to planting grass, or wherever it is necessary to accumulate sand. In these cases it may be advantageous to have the fences higher than when they are intended primarily to bind the sand. Sand fences are sometimes used along the base of dunes near the strand, where grass will not grow on account of occasional high tides (Pl. VIII, fig. 1).

In place of sand fences heather or brush placed in rows or squares and held in place by a little sand thrown over one edge is sometimes used.

FORESTATION.

The processes previously described are as a rule only preparatory to establishing a forest. When the dunes are covered with trees they are permanently fixed, and the trees being cared for according to the usual regulations pertaining to forest management become a source of revenue to the Government. It appears that most of the large and troublesome dune areas along the coast were at one time covered with forest, notably Holland and the Kurische Nehrung, but through lack of foresight these areas were denuded of forest and ere long were converted into wastes of drifting sand. Some attempts were made in the early part of the last century to reforest these areas by sowing the seed of forest trees. These trials all resulted in failure, although there are here and there in protected situations small and stunted groves which survived. It has been proved that the only satisfactory method of establishing a forest in the northern dune areas is by setting out young trees, after the sand has been fixed by one of the methods described in previous paragraphs. In Gascony on the southwest coast of France, however, the forest has been successfully established from seed under conditions which will be described when speaking of the methods used in that country.

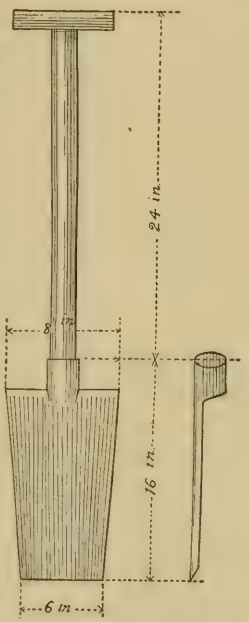

FIG. 9.—Spade used in Prussia for transplantiag young trees.

The trees used are mostly conifers, the species depending upon the locality. In the Netherlands *Pinus austriaca* and *P. laricio* are most successful on the coast and *P. sylvestris* on the interior dunes; in Denmark *Pinus montana* on the coast and *Picea excelsa* (preceded by *Pinus montana*) on the interior "heide;" *Pinus sylvestris* and *P. montana* on the Kurische Nehrung; and *Pinus maritima* in Gascony. Deciduous trees, such as birches, alders, and oaks, are used along the roads and serve as fire guards.

The seedlings are raised in nurseries located at convenient points near the area to be planted. These nurseries are often surrounded by wire netting to keep out rabbits and other harmful animals, and may also be protected from the wind by wind-breaks of reeds or cut branches of pine.

The young trees are transplanted when one or two years old (fig. 9). The growth is often quite slow at first and the young forest needs much attention. Some of the trees die and these must be replaced. But on the whole these operations have been very successful, and now there are several areas of forest that are producing an income to the Government.

FIXATION AS OBSERVED IN EUROPE.

For the purpose of observing the details of the European processes of dune reclamation as actually practiced, the Netherlands, Denmark, Germany, and France were visited. Below are given the details of the methods used in the countries mentioned, which may be taken as fairly typical of the work throughout Europe.

THE NETHERLANDS.

Through the kindness of the American minister at The Hague, Mr. Newel, and Mr. Van Marez Oijens, the minister of the department of waterworks, a detailed examination of the dunes near Alkmaar and in the vicinity of Barneveld was made.

COASTAL DUNES.

A line of dunes extends all along the coast of the provinces of North Holland and South Holland. These are two of the richest provinces in the Kingdom, and it becomes of great importance to prevent the encroachment upon the agricultural lands which lie just back of the coast. The dunes were visited in company with Mr. Van Dissel, who has charge of this portion of the work, and who explained the details of the methods used at that point. The particular portion of the dunes visited was near the little town of Schoorl. The land to be reclaimed was the property of the General Government. At an earlier period this region was covered with forest trees, but these were cut off to be used for fuel and other purposes. The result was disastrous. The covering of vegetation was broken through, allowing the wind access to the sand, and finally the whole area was converted into a series of shifting dunes. About forty years ago an attempt was made to reforest these dunes by sowing the seed of pines. These seeds seem to have germinated quite readily, but the seedlings were unable to withstand the severe conditions, and now all that remain to show for the work are a few isolated groves in protected places. The Government has now planned an extensive system of reclamation which in time will convert all of this waste into a productive forest.

The preliminary fixation is done by planting beach grass, as indicated in a previous paragraph. (See Pl. VII, fig. 1.) In this region there is no inert covering that can be economically used, but beach grass grows abundantly all along the coast. As it is easier to obtain the necessary labor in the autumn, the planting takes place at this season rather than the spring. Furthermore, it is easier in the autumn for unskilled laborers to choose grass of the proper age for planting, as in the spring the portion above ground is dried and brown, thus making it difficult to distinguish between the shoots of different ages. Care is taken to gather grass for planting from places where it is growing thickly, so as not to rob the sand of its covering to an

injurious extent. In gathering the grass a short-handled spade is used. The little bunches are tied in bundles of 72, this being a convenient armful and also a convenient number for calculation, six dozen. The planting is done by two persons working together, as already described. Sometimes the sand is pressed back upon the transplanted grass by means of the foot instead of the first worker using the spade. While a handful is more than necessary, experience has shown that some of the grass fails to grow. Even though it does not grow, the dead grass acts as a barrier to the sand for some time, at least one year. The grass is planted in rows about 40 centimeters (16 inches) apart and 30 centimeters apart in the row, the bunches in successive rows alternating. If the sand is not entirely bare, the bunches are planted here and there where they are needed. Ordinarily no attempt is made to level or alter the ground and in many places steep hillsides are planted. However, there are cases where the land is somewhat prepared, especially by leveling sharp points that rise above the general surface. In the region visited there is no protecting dune along the strand, and such a method of protection seems not to have been used in Holland.

After the sand has been planted to grass to prevent its drifting, the trees are set out. The young trees are grown in nurseries from seed planted usually in April. Trees are set out when one or two years old in spring or fall, according to conditions. Several species have been tried, such as *Abies balsamea* Mill., *Pinus austriaca* Link, *P. laricio* Poir., *P. maritima* Lam., *P. rigida* Mill., *P. sylvestris* L., *Quercus pedunculata* Ehrh., *Q. rubra* L., and *Robinia pseudacacia* L.

It has been found that the species best adapted for exposed situations are *Pinus austriaca* and *P. laricio*. Some other pines, especially *P. sylvestris*, are good for the more sheltered places.

The cost of setting the grass is 50 to 75 guilders[a] per hectare, and the total cost of reforesting is about 150 guilders per hectare (about $22 per acre). It must be remembered, however, that labor, the most important item of expense, costs much less than in the United States.

INTERIOR DUNES.

In company with Mr. Jager-Gerlings, an interior dune area in the Province of Gelderland, east of the town of Barneveld, was next visited. This is known as heath land because heath or heather (*Calluna vulgaris*) is abundant here. The Government has purchased a quantity of this waste land and proposes to convert it into forest. The land is sterile and the country almost uninhabited.

Here the preliminary fixation is by means of covering the sand with layers of cut heather. The heather is cut with a short, thick scythe

[a] A guilder, gulden, or florin is worth about 40 cents in American money. A hectare is equal to 2.471 acres.

with a straight handle, tied in bundles about 1 meter in circumference, and carried to the place of use in carts or wagons The hills are covered with the layers of heather described in the first part of this article (Pl. II, fig 1).

The region consists of dunes more or less bare and shifting, alternating with lower moist areas where there is a covering of vegetation, mostly heather. These low areas are sufficiently moist to keep the sand from drifting. Experience has shown that over much of this area trees do not thrive when set out in holes, as is customary. This seems to be due to the lack of air in the soil. It has therefore been found necessary to spade up the soil before the trees are planted. This is done by digging up the soil to a depth of 0.56 meter (about 22 inches). It is unnecessary to spade up the soil over the entire surface, the digging being confined to strips 1.2 meters wide, with an unspaded space of 0.8 meter lying between.

The trees are planted in rows, one near each margin of the spaded strip and 0.75 to 0.80 meter apart. Heather is laid between the rows to hold the sand. On the hills where the heather has been laid the trees may be planted in holes among the heather. The planting takes place in autumn or spring, but it is customary to plant the hills in the fall, leaving the low places till spring, when it is drier (Pl. II, fig. 1; Pl. III, fig. 1).

After the planting it is necessary to watch the growth of the trees and to stir the ground around them in proportion to their needs. If the growth is poor and the trees remain stunted the ground is stirred with a stout four-tined rake. If the soil is moved too much the trees may make too vigorous a growth and the wood will not ripen sufficiently in the fall.

The tree best suited to the greater part of this region is the common pine or, as it is called in America, the Scotch pine (*Pinus sylvestris*). It was stated that the trees from Scottish seed grew better than those from Norway seed.

On the more sterile portions of the area better results are obtained from *Pinus rigida* and *P. divaricata* Gord. (*P. banksiana* Lam.). The black or Austrian pine (*Pinus austriaca*) does not succeed well, its growth being too slow. *Pinus laricio* promises well.

About one-fourth of 1 per cent of the trees die from various causes, and these it is necessary to replace. Various insects prey upon the trees. In this connection it is noteworthy that bird houses are placed at intervals in the forest to attract birds that devour harmful insects or their larvæ. A bird called the "birkhuhn" nips off the young buds. Rabbits and other small animals gnaw the bark. A root fungus (*Agaricus melleus*) kills many individuals. These are replaced by choke-cherry (*Prunus virginiana*).

The cost of the work per hectare at this point is approximately as follows:

	Guilders.
Cutting and tying the heather	1.1
Transporting the heather	1.5
Spreading the heather	16
Spading the ground	57
Planting the trees	25

This makes the total cost about 100 guilders per hectare, or about $16 per acre.

The different parts of the plantation are reached by means of roads placed at convenient distances. There is usually a strip of deciduous trees, mostly of birches, planted along these roads as a protection in case of fire, since conifers burn with ease, while the birches do not. In passing through the higher dunes, it is necessary to have the roads curve between them in order that the wind may not sweep through and cause serious erosion.

DENMARK.

Through the kindness of Prof. Eugene Warming, director of the botanical garden at Copenhagen, letters of introduction to the dune inspectors at Aar and Skagen were obtained. Dune areas extend all along the coast of western and northern Denmark, but these two points were selected as being typical of the entire region.

OXBÖL.

The first point visited was in the southwestern part of Denmark in the Province of Ribe. Mr. R. P. F. Bang, the inspector of this district, lives at Aar, near Oxböl, which is reached via Esbjerg and Varde. The method used here for fixing the sand and planting trees is similar to that used in Holland; the conditions are also very similar. The region consists of a series of sand dunes, with low places interspersed, and extends some distance back from the coast. There has been no attempt in this region to form a barrier dune. As the heather grows abundantly throughout most of the dune region this plant is used for the purpose of fixation except near the coast. The young forest consists for the most part of *Pinus montana* and *Picea alba*. In addition, Mr. Bang has experimented with *Picea sitchensis* and *P. nordmanniana*, both of which promise success. *Pinus austriaca* is injured by the cold winters, and *Picea excelsa* does not successfully withstand severe winds. On certain portions, where the soil is comparatively rich, *Picea pectinata* succeeds.

About fifty years ago an attempt was made to establish a forest in this region, and in certain isolated and protected places portions of this forest are now in evidence. The trees, according to the situation,

may be 3 to 15 feet high, but for the most part present a very stunted growth.

The heather is laid at any time of the year when it can be most conveniently done.[a] Near the coast, where beach grass is used, the planting takes place as in Holland except that on account of the broken nature of the country and the strong winds it is found that the bunches of grass must be smaller, consisting only of one or two pieces. The pines are planted when they are 3 years old and the spruces at 4 years. The plantation showed a very marked difference in the condition of the trees, depending on the richness of the soil and the exposure. The stunting of the trees is very noticeable in the native forest near the coast. The trees nearest the coast are small and scrubby, and for some distance inland they bear very few branches on the windward side, therefore appearing very lopsided. The entire cost of laying the heather, planting and raising the trees, is 300 crowns per hectare,[b] or about $32 per acre. The usual compensation for planting the grass is about 8 cents per square rod, the work being done at a fixed price (4 öre) per 4 square meters.

SKAGEN.

The investigation of the dunes around Skagen at the north end of Denmark was made in company with the inspector, Mr. C. F. Dahlerup. The whole peninsula above Frederikshavn is one vast sand area consisting mostly of dunes. Between the dunes are more or less extended areas of flat land where the soil contains more humus. These lower portions can be used for grass and to a limited extent for other crops, but they must be fertilized and limed. For this purpose kainit and Thomas slag are used, and lupines are grown to supply nitrogen. The distance to the ground water determines the availability of the soil for crops, the most favorable distance being about 18 inches. If the ground water lies lower than this the soil is too dry and if above this it is too wet for cultivation. The land around Skagen and for about two miles south is owned privately, but a large area south of this is owned by the Government. The latter is carrying on a system of reclamation upon this area, and also upon some of the land owned privately. Upon the private land the cost is divided as follows: One-half is paid by the General Government, one-sixth by the province, one-sixth by the township, and one-sixth by the owner.

The preliminary fixation is by means of beach grass planted in October or November. Although in the more quiet portions of the dune the beach grass lives only from five to ten years, yet as it gradually dies out its place is taken by various native plants which serve to

[a] The methods used in planting have been described in Tidskrift for Skoving, 12, Om de Nord-og vestjydske Klitters Beplantning.

[b] A crown equals 26.8 cents in American money.

hold the sand effectively. Heather also lasts about the same time, but the native plants tend to take its place as it disintegrates. One of the common plants found as a native covering is reindeer moss. *Salix repens*, one of the willows, is an excellent plant for holding the sand, but thus far there has been no success in its artificial propagation. On the large areas of beach-grass plantations the rows follow the contour lines and the planting extends from the base toward the apex of the hills, but the tops of the dunes are not planted. The cost of planting and gathering the grass is about the same here as around Oxböl. It is customary to hire one workman at a fixed price per square yard, and this man provides the necessary helpers.

The trees used here upon the plantation are mostly *Pinus montana* and *Picea alba*. *Picea sitchensis* has been used to some extent and seems to do well, especially in wet places, but it has not yet been sufficiently tested. *Picea alba* withstands wind but will not endure drought. The seed of the trees is planted in seed beds in May. The following spring, when the seedlings are one year old, they are transplanted to the nursery rows by an ingenious machine. It was said that by means of this machine 1,000 plants could be transplanted at a cost of about 6 cents. The trees are finally set out upon the dunes when they are three years old. Besides the conifers mentioned, oak (*Quercus sessiliflora*) and birch are employed as fire guards. It is interesting to note that the heather comes in naturally in the birch plantations, but does not appear in the oak plantations. Alder is planted on low places for the purpose of enriching the land, the nodules upon the roots having the same function as those upon the roots of legumes. Mr. Dahlerup stated that there are in all about thirty-five plantations in Denmark along the west coast of Jutland, one of the largest being this one at Skagen. Concerning the interior plantations in the "heide" region, he said that the preliminary fixation is by means of heather, while the young forest is composed of *Pinus montana* and *Picea excelsa*. The latter is the best tree for the purpose, but it can not be grown successfully directly upon the heather land. It is therefore necessary to plant first *Pinus montana*. This kills the heather and *Picea excelsa* can be made to grow in the shade of the pine. Although *Pinus montana* can be successfully grown, it is inferior to *Picea excelsa* so far as its usefulness for timber purposes is concerned.

GERMANY.

The most extensive work to be found in Europe in the reclamation of sand-dune areas has been done along the north coast of Germany. The coast of the North Sea, and especially the North and East Friesian Islands, are continually subjected to the erosive action of wind and water, which requires not only extensive work in the protection and reclamation of dunes but much in the way of mechanical obstruction.

The coast and harbors are protected in various ways by masonry and piles. Sand-dune works also extend in various places all along the coast of the Baltic Sea, which, however, are fully described in Gerhardt's book, previously mentioned. Therefore, for the purpose of inspecting the methods which are typical of the whole coast, a visit was made to only one of the important sand-dune regions of Germany—the Kurische Nehrung in northeastern Prussia.

This is one of the most wonderful sand spits in the world, consisting of a narrow peninsula which extends northward from the region of Kranz for about 60 miles. To the west lies the open ocean of the Baltic Sea and to the east the bay called the Kurisches Haff. The opening to the bay lies just to the north of this sand spit. On the opposite shore is located the somewhat important town of Memel, and there are three or four towns or villages situated in various places along the peninsula. The strip of land is quite narrow, varying from 1 to 5 miles in width. At one time this peninsula was covered with forests, but later the trees were removed and the region was soon converted into a series of shifting dunes. Besides the necessity for protecting the villages and arable land upon the peninsula it is necessary to prevent the increased encroachment of the sand upon the harbor to the east. For these reasons the Government undertook the reclamation of the whole peninsula.

So much attention is given to this region in Gerhardt's work that it is unnecessary to do more than note a few points in which the methods differ from those used in the Netherlands and in Denmark. In the first place, a long barrier dune, the entire length of the peninsula on the west side, has been produced. This is kept in repair by means of beach grass and the necessary sand fences. The beach grass is planted upon this dune in a much more exact and methodical manner than that seen elsewhere. The surface is first carefully laid off with a line in squares called "quadrats," and the plants are placed with almost mathematical precision. The forest consists for the most part of *Pinus montana*. In the vicinity of Rossitten there are several large wandering dunes which have not been planted. These dunes are indeed hills, being from 200 to 300 feet in height. As the general course of these shifting dunes is from the west toward the east, they will finally disappear in the waters of the Kurisches Haff. For this reason it has been thought inexpedient to make plantations upon them except where it has been necessary to protect villages and other valuable property.

Through the kindness of Prof. Christian Luerssen, who gave a letter of introduction to the dune inspector of this region, the venerable Mr. Epha, a veteran in the service of sand reclamation, every pains was taken to render the inspection of the dunes easy and satisfactory. The success of the work in this region is impressive. The conditions

are certainly as adverse as on any of the dune areas along the European coast; yet the vast sandy waste has been converted into a productive forest, which, with a comparatively small amount of attention, can be protected from further encroachment of the ocean.

The cost of holding the sand by planting grass upon the wandering dunes of the Kurische Nehrung is said by Gerhardt to be from 170 to 220 marks[a] per hectare, or $17 to $22 per acre. This includes gathering the grass, transporting it to the plantation, and the setting The gathering costs from 2 to 2.50 marks, while the transportation costs about 2 marks per 100 bundles for distances not exceeding 3 miles and about 3 marks where the distance is 3 to 5 miles. Planting is usually done by the day, the wages paid being 1.30 to 1.80 marks for men and from 1 to 1.20 marks for women. The laborers are mostly women (Pl. VII, fig. 2). According to circumstances the cost of planting 100 bundles may be 3 to 8 marks. Where the grass to be used is obtained in the vicinity by thinning the dense bunches the total cost of planting may be 5 to 10 marks per 100 bundles.

The cost of the brush fences, where this method is used, is about 0.20 mark (5 cents) per running meter. This includes gathering the brush, preparing the stakes, and setting the fence. As the material is obtained from the waste brush in the neighborhood, no charge is estimated for this. The amount of material is at the rate of 0.05 cubic meter per running meter. At this rate one cord of the prepared brush is sufficient to set about 80 yards of fence.

The cost of establishing a forest is given by Gerhardt as 1,200 marks per hectare ($120 per acre). This is the average of ten years' experience upon the Kurische Nehrung and includes items as follows:

	Cost per hectare.	Cost per acre.
	Marks.	*Dollars.*
Fixation of the shifting sand by means of sand or reed hedges	700	70.00
Fertilizer	300	30.00
Preparation of the holes for planting	50	5.00
Planting the young trees, 400 to the hectare	125	12.50
Miscellaneous expenses	25	2.50
Total	1,200	120.00

FRANCE.

The most important dune region in France is that along the southwestern coast from the vicinity of Bordeaux to the Spanish line. Through the courtesy of Mr. Poisson, a botanist in the Jardin des Plantes, a letter of introduction to Mr. Émile Durègne, a civil engineer living in Bordeaux, who has been over the greater part of the dunes

[a] A German mark is equal to 23.8 cents in American money.

in his capacity as surveyor, was provided. Mr. Durègne is very familiar with the whole region and with the methods which have been used to reclaim it, and has published some important papers upon the subject. The particular region visited was a few miles south of Arcachon. This is a part of the general dune system extending from the mouth of the Gironde River to Bayonne. Before this land was reclaimed a considerable portion lying back of the dunes was unfit for agriculture, as it consisted of alternating sand hills and marshes. Since the reclamation the conditions have so changed that the population has very materially increased. A barrier dune, similar to the one found in the Kurische Nehrung, extends all along the coast (Pl. VI, fig. 1). This is held in place in the same manner; that is, by means of beach grass and brush fences. The most marked difference in the method of reclamation is in the fact that a forest was established by sowing the seed. The seed of *Pinus maritima* is sown on the sand in October or November or in the spring during March and April, and the whole is then covered with brush or conifers. The seed soon germinates, and, protected temporarily by the brush, grows into a forest.

The total cost of covering the area with forest, including the planting of the trees and the covering of the land, is about 320 francs per hectare, or about $26 per acre. The grass for planting the barrier dune is dug up by means of a small mattock, and is set with a conical instrument having a horizontal handle. The grass is planted in rows parallel to the course of the dune. Breaches are repaired by means of sand fences (Pl. IV, fig. 2), usually by placing two lines of fence about 6 meters apart and extending above the surface of the sand 60 or 70 centimeters. As soon as these are covered a second line of fence is placed on top. The fence which was used in establishing the original barrier dune was placed about 2 meters high. Where ravines are to be filled with sand it is common to use these fences in a network of squares. Some portions of this protecting dune reach the extraordinary height of 200 feet or even more. There is evidence to show that in former times some of these dunes had encroached upon the inland forest, killed the trees, and then passed over them, as stumps are to be found on the windward side along the shore (Pl. V, fig. 2).

Mr. J. Poisson[a] has described the method used upon the dunes of the Coubre, a peninsula which lies just north of the mouth of the river Gironde. The seed of *Pinus maritima* was sown at the rate of about 5½ pounds to the acre, mixed with one-half pound each of furze, broom, and beach grass. The total cost of covering 2,100 hectares was 766,142 francs, or about $29 per acre.

[a] Sur la fixation des dunes dans l'ouest et dans le nord de la France. Extrait des Comptes Rendus de l'Association Française pour l'Avancement des Sciences. Paris, 1900.

Mr. John Gifford, who has examined the dune region of the Landes, gives an account[a] of the methods used in the original work of reclamation, which is here appended:

A littoral dune was constructed straight along the shore from the mouth of the Gironde to Bayonne. This dune is the secret of all success in the fixation of shifting sand. It is simply a bank of sand of certain dimensions, with a certain slope suited to the condition of affairs. This protective, or littoral, dune is formed as follows: A double fence is constructed of brush, or of palisades driven in the sand. This stops the sand which comes from the ocean. Soon a ridge of sand forms, equal in height to the fence. A double fence is used, as it gives breadth to the dune and stops the sand which blows through the fence on the ocean side. As soon as a ridge of sand is formed as high as the fence, the old fence is pulled up or a new one built on top, and so on until a dune of the height desired is formed artificially. The proper height of a protective dune is 33 feet. It should slope 25 degrees toward the sea, and may be 60 degrees[b] on the land side. The dune must be at least 300 feet from high-water mark. After the dune has reached the proper size, it is kept in shape by the sea marram (*Psamma arenaria*).[c] This peculiar plant, called gourbet in France, is exclusively used for fixing the sand on the littoral dune. It has long, much-divided rhizomes, and will grow well only when covered with fresh sand. The dune must always be kept in shape. If sand accumulates in any one spot in undue amount, a draft is formed, which may end in a breach of the littoral dune. "Gardes cantonniers" are stationed along the dune to watch it closely, and here and there on this long, straight sand bank groups of men and women may be seen digging up the gourbet in places where it is too thick and planting it where needed. Constantly the dune is watched and mended; the forest, villages, and fields in its lee are dependent upon it, and it in turn is dependent upon the humble but persistent gourbet.

After the formation of the littoral dune comes the work of planting in its lee. The surface of the sand is covered with brush arranged like the slates on a roof, with a shovelful of sand here and there to hold it down. Then the seeds of *Pinus maritima* are sown, with seeds of other plants to shade the young pines, and seeds to attract insectivorous birds. The pines usually come up well and grow quickly, although close to the littoral dune they are gnarled and stunted by the salt winds. Thus the sands are fixed, and, although the forests do not yield a good interest in cash, they are of incalculable value to a large proportion of the people of Gascony; in fact, indirectly, to the whole of France. Fire lanes have been constructed across the dunes, and, thanks to the watchfulness of the guards and the rigid enforcement of laws, fires are almost impossible.

Very little cutting is done in these forests, the revenue coming mainly from the resin industry. Owing to a lack of roads and insufficient means of transportation on these dunes, only the most valuable timber is marketed, after being tapped for resin. If it is desirable to remove a tree, it is bled to death before being cut. All other trees are tapped very carefully, and are in no way injured by the process. In fact, bled timber is considered superior to unbled in France. The Hague method of orcharding is used, a system which does not injure the tree, but gives a resin of better quality and more abundant turpentine. Another article, however, could be written on the French method of turpentine orcharding.

Other industries have started, the people have improved, and the country is more fruitful and beautiful, so that through the agency of trees a new province has been practically added to France.

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[a] The Control and Fixation of Shifting Sands. In the Engineering Magazine, January, 1898.

[b] There is some error here in the angles given for the slope. The windward slope is from 4 degrees to 14 degrees, and the lee slope about 30 degrees.

[c] Another name for beach grass (*Ammophila arenaria*).

SUMMARY.

Extensive and systematic work is done by various governments in Europe for the purpose of reclaiming waste dune areas. The object may be to convert this waste into a productive forest, or to prevent the encroachment of the sand upon valuable property.

The sand is first held in place by some inert covering or a plantation of grass, and afterwards a forest is established by transplanting young trees.

Trees will not grow in the immediate vicinity of the ocean; hence a narrow strip along the coast must be permanently held in place by means of a sand-binding grass.

The best grass for this purpose is beach grass (*Ammophila arenaria*), which grows naturally along the sandy seashores of the North Atlantic coast. The same species grows along the shores of the Great Lakes and on the Atlantic coast of the United States as far south as North Carolina.

The grass is transplanted in rows or squares in autumn or spring. Satisfactory results can not be produced by sowing the seed of this or of other plants directly upon the unprotected sand.

Where heather grows in sufficient abundance this is cut and laid upon the surface of the sand.

The third important method for preventing drifting is the use of sand fences. These consist of rows of rough stakes or pieces of brush driven into the sand and projecting above the surface from 1 to 3 feet. For holding the sand the shorter stakes are placed in squares of 9 to 12 feet, forming a network. For accumulating sand in hollows or repairing breaches in a protecting dune the high fences may be used. Solid fences are not used.

The drifting of the sand having been prevented by one of the above methods, young trees are set out to form the permanent covering of forest. In northern Europe no satisfactory results have been obtained in establishing a forest by sowing the seed, but in southwestern France a forest was produced by sowing the seed of *Pinus maritima* upon the sand and covering it with brush.

The trees used are: In the Netherlands, *Pinus austriaca* and *P. laricio* near the coast, *P. sylvestris* on the interior dunes; Denmark, *Pinus montana* near the coast and *Picea excelsa* (preceded by *Pinus montana*) on interior heath land; Germany, *Pinus montana;* France, *Pinus maritima.*

On the Kurische Nehrung and in other parts of Prussia, and in Gascony, a long barrier dune has been formed artificially to protect the land lying back of it. This is kept in repair by planting beach grass and by the use of sand fences when necessary.

PLATES.

DESCRIPTION OF PLATES.

PLATE I. *Frontispiece.* Beach grass (*Ammophila arenaria* Link). Drawing from herbarium specimen.

PLATE II. Fig. 1.—Inland dunes near Barneveld, the Netherlands. In the background the dunes have been covered with heather to prevent drifting and afterwards set out with *Pinus sylvestris.* In the foreground the pines have been planted without a covering of heather, as the sand is here moist enough to prevent its drifting. Fig. 2.—Inland dunes near Barneveld, the Netherlands, showing road in process of construction through the plantations. In the background the dunes are covered with heather. In the foreground is the road, the sand being ridged up with ditches at each side. Upon the sand is placed heather in a thick layer. This prevents the wheels of vehicles from sinking into the loose sand.

PLATE III. Fig. 1.—Inland dunes near Barneveld, the Netherlands, showing a plantation of *Pinus sylvestris* on a covering of heather. The sand is first covered with a layer of cut heather to prevent its drifting. Fig. 2.—Unreclaimed sand dunes near Alkmaar, the Netherlands. In the foreground is a low area partially covered with heather. In the interior such areas furnish the heather, which is cut and laid upon the surface of the sand to prevent its drifting.

PLATE IV. Fig. 1.—Plantation of beach grass upon the dunes near Oxböl, Denmark. This shows how the plantations are made along the lower places and part way up the slopes of the dunes, the tops remaining unplanted. The grass will be planted somewhat higher on the slopes as opportunity permits, but the tops will be denuded of grass to facilitate the removal of the sand by the wind. Fig. 2.—Barrier or protecting dune south of Arcachon, France. To the left beach grass has been planted in rows parallel to the beach. In the center is a sand fence, placed to repair a breach, which is now nearly covered with sand. To the extreme right is the forest in the lee of the dune.

PLATE V. Fig. 1.—Lee slope of a portion of the barrier dune south of Arcachon, France. Since the dune has been fixed on the windward slope, the advance of the sand inland has been very slow, as shown by young trees growing along the slope. Fig. 2.—Unreclaimed sand dunes south of Arcachon, France. The stumps are the remains of a forest which has been covered and again uncovered by an advancing dune.

PLATE VI. Fig 1.—General view of the barrier dune south of Arcachon, France. This dune stretches along the coast from Arcachon to Bayonne, about 75 miles, and protects the forest of *Pinus maritima* in its lee at the right. The ocean is seen at the left. This dune was formed artificially with the help of sand fences and beach grass and is now held in position by the same means. [From a photograph by Mr. É. Durègne.] Fig. 2.—Unreclaimed sand dunes south of Arcachon, France. The sand is drifting badly at this point. Here and there a small hillock is held in place by a bunch of beach grass.

PLATE VII. Fig. 1.—Laborers digging beach grass near Alkmaar, in the Netherlands. The instrument used for this purpose here is a spade with a rounded point. The grass is obtained upon the dunes where it is growing naturally, by thinning out the bunches. In the background may be seen the unreclaimed dunes partially covered with vegetation. Fig. 2.—Laborers setting out beach grass upon the barrier

dune at Rossitten, on the Kurische Nehrung. At the right is the overseer. The grass is set in squares or "quadrats." The position of the rows is determined quite accurately by stretching a line between two poles, one of which appears in the illustration. One laborer makes the holes with a planting spade, while another sets the grass. At the left may be seen a bundle of the grass ready to be set.

PLATE VIII. Fig. 1.—Protecting the base of a barrier dune by means of two rows of sand fences. Storms had eaten away the face of the dune and the fences are placed to accumulate sand, after which grass will be planted. [From a cut in Gerhardt's Dünenbau.] Fig. 2.—Protecting a road through the dunes, on the Frische Nehrung, Prussia. The road is curved and the slope is held by covering with a layer of reeds and placing poles upon these. [From a cut in Gerhardt's Dünenbau.]

PLATE IX. Fig. 1.—Shifting dunes held by sand fences on the Kurische Nehrung, Prussia. The fences are of brush placed in squares. Nearer the strand the brush is in rows parallel to the beach. [From a cut in Gerhardt's Dünenbau.] Fig. 2.—Shifting dunes held by means of sand fences of reeds, on the Kurische Nehrung, Prussia. Next to the strand the reeds are placed in rows parallel to the beach. Farther up on the dunes they are placed in squares. A roadway passes through at this point. [From a cut in Gerhardt's Dünenbau.]

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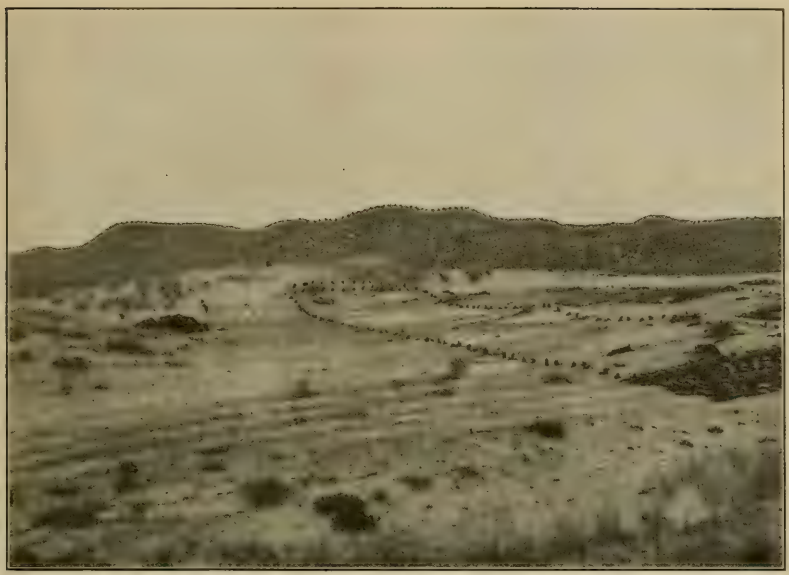

FIG. 1.—DUNES HELD BY COVERING OF HEATHER.

FIG. 2.—MAKING A ROAD IN THE DUNES.

FIG. 1.—PINE PLANTATIONS IN COVERING OF HEATHER.

FIG. 2.—HEATHER AMONG THE DUNES.

FIG. 1.—BEACH GRASS PLANTATION ALONG BASE OF DUNES.

FIG. 2.—BEACH GRASS AND SAND FENCE ON BARRIER DUNE.

FIG. 1.—LEE SLOPE OF BARRIER DUNE.

FIG. 2.—REMAINS OF ONCE BURIED FOREST.

FIG. 1.—GENERAL VIEW OF BARRIER DUNE.

FIG. 2.—UNRECLAIMED SHIFTING DUNE.

FIG. 1.—DIGGING BEACH GRASS FOR PLANTING.

FIG. 2.—TRANSPLANTING BEACH GRASS.

FIG. 1.—SAND FENCES PROTECTING BASE OF DUNE.

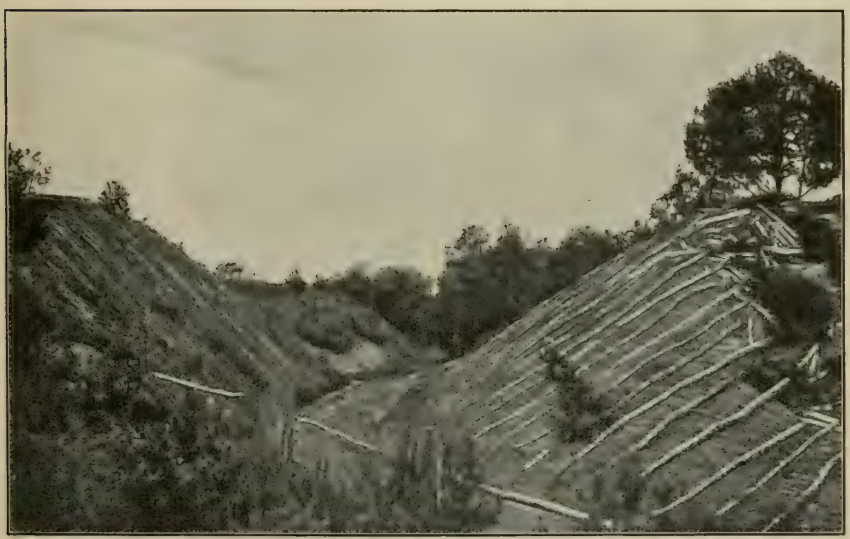

FIG. 2.—PROTECTING A ROAD THROUGH THE DUNES.

FIG. 1.—SHIFTING DUNES HELD BY BRUSH FENCES.

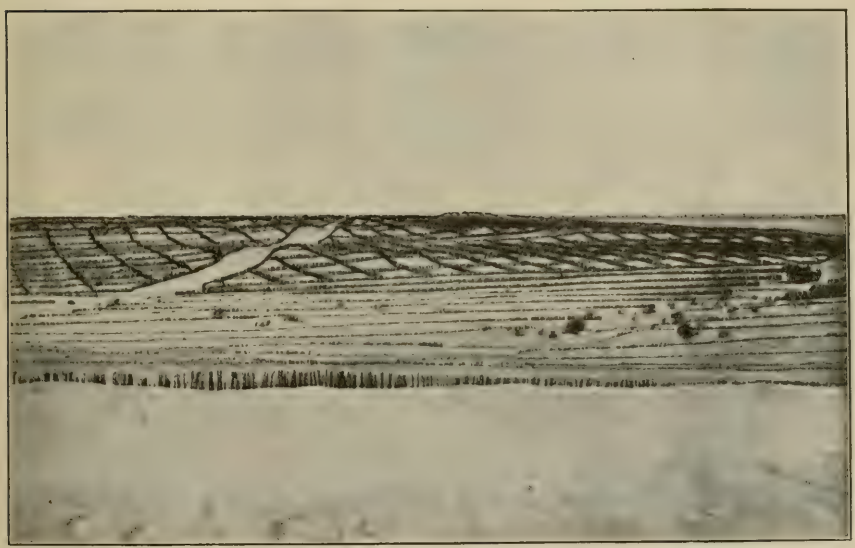

FIG. 2.—SHIFTING DUNE HELD BY REED FENCES.

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